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Effect of lateral heel wedges on sagittal and transverse plane kinematics of trotting Shetland ponies and the influence of feeding and training regimes

W. BACK*, J. L. M. A. REMMEN[†], J. KNAAP[‡] and J. J. DE KONING[§]

Department of Equine Sciences, Faculty of Veterinary Medicine, Utrecht University, Yalelaan 12, NL-3584 CM Utrecht; [†]Netherlands Shetland Pony Studbook, Dr. Hoekstraat 3, NL-5268 EM Helvoirt; [‡]Research Institute for Horse Husbandry, Runderweg 6, NL-8219 PK Lelystad and [§]Faculty of Human Movement Sciences, Free University Amsterdam, vd Boechorststraat 9, NL-1081 BTAmsterdam, The Netherlands.

Keywords: horse; shoeing; lameness; patella fixation; patella luxation; bone spavin

Summary

Reasons for performing study: **Lateral heel wedges are used to treat horses and ponies with patella fixation or bone spavin. However, these therapies are purely empirically based and lack scientific evidence.**

Objectives: **Lateral heel wedges would change joint motion in the sagittal, but mainly in the transversal planes, in healthy horses. This effect would be increased by restricted feeding and decreased by extra training.**

Methods: **A group of 24 Shetland ponies age 3 years was used, as foals had been assigned to restricted and *ad libitum* (*ad lib*) feeding, and low and high level training groups of 6 animals each. An experienced judge evaluated passive patella luxation in the square standing pony, using a score of 0 (normal) to 4 (stationary patella luxation). The motion of the markers, glued to the skin covering skeletal landmarks on the left fore- and hindlimbs, was recorded 3 dimensionally at a frequency of 300 Hz using a modified CODA-3 apparatus while trotting on a treadmill at a speed of 3.0 m/sec, before and directly after 5° lateral heel wedges had been applied to the hindlimbs. After data analysis, the kinematic variables in the sagittal and transversal plane, under these 3 conditions (wedge, feeding, training), were compared statistically using a multivariate repeated measures analysis, general linear model ($P<0.05$).**

Results: **In the sagittal plane, an acute change in hind hoof conformation resulted in a less animated trot with a less protracted forelimb and less hindlimb flexion. This is similar, although less pronounced, to the decrease in limb flexion reported previously as a result of restricted feeding. More specifically, lateral heel wedges resulted in significant changes in the transversal plane angles of all joints in the hindlimb. The stifle joint became maximally 1.8° more adducted just before the end of the stance phase, while the tarsal joint was 2.9° and fetlock joint 4.7° more abducted ($P<0.05$). In the restricted feeding group, stifle joint adduction was 8.5° and tarsal joint abduction 5.6° larger than in the *ad libitum* feeding group ($P<0.05$). The patella luxation score was also significantly higher in this group (1.8) compared to ponies fed *ad libitum* (0.9).**

Conclusions: **The acute effects of lateral heel wedges on the equine locomotor system in the transversal plane movement relieve tension from the medial patellar ligament and decrease pressure on the medial side of the tarsal joint. However, the fetlock joint experiences considerably more out of plane stress. Poor body condition resulted in a 2x worse patella luxation score, while the effect on stifle and tarsal joint movement in the transverse plane was almost 5x and 2x larger, respectively, than a lateral wedge.**

Potential relevance: **The clinical importance of general body condition for maintaining lateral stability in the equine hindlimbs is established, but future research may prove that wedges are beneficial to treat patella fixation and bone spavin in the long term.**

Introduction

Lateral heel wedges have long been used to treat horses and ponies with patella fixation or bone spavin, but this practice has little scientific basis (Stashak 1987; Butler 1995). Colahan *et al.* (1991) and Wilson *et al.* (1998) reported that the static centre of pressure at the hoof shifts in the direction of the wedge, while Firth *et al.* (1988) demonstrated that strain values at the medial side of the metacarpus temporarily decrease in foals with lateral heel wedges. Caudron *et al.* (1997) and Chateau *et al.* (2001) studied *in vitro* effects of wedged foot imbalance on the coffin and metacarpophalangeal joint angles. To our knowledge there is no objective information available about the effects of these wedges on important variables, such as tarsal and stifle joint motion in the sagittal and transverse plane. Back *et al.* (2002) studied the effect on sagittal fore and hindlimb kinematics of training and feeding an energetically rich diet to growing Shetland ponies resulting in an obviously high body condition score. The Shetland pony is an excellent breed for this purpose as it is genetically adapted to survive the harsh conditions on the Shetland Islands and, therefore, is easily overfed under less demanding conditions in our 'horse as a companion animal' society. Stifle joint motion problems, e.g. patella fixation and luxation, are also common in Shetland ponies and are, in most cases, treated initially by giving training advice to increase muscle strength (Hermans *et al.* 1987; Stashak 1987).

*Author to whom correspondence should be addressed.

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TABLE1a: Sagittal plane kinematic variables of the forelimb of the total group of 23 Shetland ponies trotting on the treadmill at a speed of 3.0 m/sec before and after wedging

	Wedge	
Forelimb	Pre-	Post
Stride duration (sec)	0.49 ± 0.03	0.49 ± 0.03
Stance duration (%)	40.0 ± 3.3	42.0 ± 5.0
Stance duration (sec)	0.196 ± 0.02	0.205 ± 0.03
Swing duration (sec)	0.295 ± 0.02	0.282 ± 0.03
Scapula rotation ampl. (°)	19.4 ± 2.4	19.7 ± 2.3
Maximum protraction angle (°)	18.8 ± 1.7	18.2 ± 1.9*
Maximum retraction angle (°)	-25.7 ± 2.4	-26.4 ± 2.8
Pro-retraction range (°)	44.6 ± 2.7	44.6 ± 2.6
Elbow angle at i.g.c. (°)	55.3 ± 6.9	58.0 ± 7.2
Maximum elbow extension (°)	27.6 ± 6.1	27.8 ± 6.0
Extension relative to i.g.c. (°)	-27.7 ± 4.4	-30.3 ± 5.6
Maximum elbow flexion (°)	83.0 ± 6.7	82.0 ± 6.5
Flexion relative to i.g.c. (°)	27.8 ± 6.3	24.0 ± 6.9*
Range of movement (°)	55.4 ± 4.6	54.3 ± 3.9
Carpus angle at i.g.c. (°)	6.2 ± 4.4	8.2 ± 7.1
Maximum carpus overextension (°)	-3.0 ± 4.2	-2.4 ± 4.0
Extension relative to i.g.c. (°)	-9.2 ± 6.6	-10.6 ± 6.9
Maximum carpus flexion (°)	82.0 ± 8.3	80.6 ± 7.6
Flexion relative to i.g.c. (°)	75.8 ± 10.4	72.4 ± 10.6
Range of movement (°)	85.0 ± 8.1	83.0 ± 7.1
Fetlock angle at i.g.c. (°)	-15.1 ± 6.4	-13.1 ± 8.4
Maximum fetlock overextension (°)	-43.4 ± 7.4	-42.9 ± 7.3
Extension relative to i.g.c. (°)	-28.3 ± 3.4	-29.8 ± 5.0
Maximum fetlock flexion (°)	27.6 ± 8.1	28.0 ± 8.2
Flexion relative to i.g.c. (°)	42.7 ± 6.0	41.0 ± 8.4
Range of movement (°)	71.0 ± 6.7	70.9 ± 6.7

i.g.c. = initial ground contact; $P<0.05$. *$P<0.005$ (including Bonferroni *post hoc* test).

TABLE1b: Sagittal plane kinematic variables of the hindlimb of the total group of 23 Shetland ponies trotting on the treadmill at a speed of 3.0 m/sec before and after wedging

	Wedge	
Hindlimb	Pre-	Post
Stride duration (sec)	0.49 ± 0.03	0.49 ± 0.03
Stance duration (%)	40.0 ± 2.7	40.5 ± 2.2
Stance duration (sec)	0.196 ± 0.02	0.197 ± 0.02
Swing duration (sec)	0.293 ± 0.02	0.288 ± 0.02
Pelvis rotation ampl. (°)	8.7 ± 0.9	9.0 ± 1.2
Maximum protraction angle (°)	19.4 ± 1.7	19.7 ± 1.4
Maximum retraction angle (°)	-24.8 ± 2.1	-24.3 ± 2.2
Pro-retraction range (°)	44.2 ± 2.5	43.9 ± 2.2
Hip angle at i.g.c. (°)	85.5 ± 6.1	85.5 ± 5.9
Maximum hip extension (°)	68.2 ± 6.4	68.8 ± 6.4
Extension relative to i.g.c. (°)	-17.3 ± 2.1	-16.8 ± 1.6
Maximum hip flexion (°)	87.2 ± 5.5	86.9 ± 5.4
Flexion relative to i.g.c. (°)	1.7 ± 0.9	1.4 ± 0.8*
Range of movement (°)	19.0 ± 2.4	18.1 ± 1.9
Stifle angle at i.g.c. (°)	30.4 ± 5.0	29.7 ± 5.2
Maximum stifle extension (°)	29.9 ± 5.2	29.1 ± 5.1
Extension relative to i.g.c. (°)	0.6 ± 0.7	0.7 ± 0.7
Maximum stifle flexion (°)	68.1 ± 6.0	66.9 ± 5.6
Flexion relative to i.g.c. (°)	37.7 ± 4.5	37.2 ± 4.6
Range of movement (°)	38.3 ± 4.6	37.9 ± 4.6
Tarsus angle at i.g.c. (°)	28.8 ± 4.1	28.3 ± 4.4
Maximum tarsus overextension (°)	17.9 ± 4.6	18.0 ± 4.5
Extension relative to i.g.c. (°)	10.9 ± 3.4	10.4 ± 3.4
Maximum tarsus flexion (°)	67.4 ± 7.0	65.0 ± 5.6
Flexion relative to i.g.c. (°)	38.6 ± 5.8	36.8 ± 5.4*
Range of movement (°)	49.5 ± 6.8	47.1 ± 4.5
Fetlock angle at i.g.c. (°)	-12.4 ± 4.8	-13.6 ± 5.1
Maximum fetlock overextension (°)	-43.0 ± 8.4	-43.1 ± 8.4
Extension relative to i.g.c. (°)	-30.6 ± 6.8	-29.5 ± 5.5
Maximum fetlock flexion (°)	36.8 ± 6.9	38.1 ± 5.4
Flexion relative to i.g.c. (°)	49.2 ± 5.0	51.6 ± 5.0*
Range of movement (°)	79.8 ± 8.8	81.2 ± 8.2
Hoof angle at i.g.c. (°)	52.7 ± 10.3	51.6 ± 10.0
Maximum stance flexion (°)	59.3 ± 9.8	63.6 ± 10.3*
Maximum hoof flexion (°)	154.8 ± 11.9	155.9 ±11.6
Range of movement (°)	102.1 ± 12.6	104.2 ± 14.1

i.g.c. = initial ground contact; $P<0.05$. *$P<0.005$ (including Bonferroni *post hoc* test).

This study was conducted in healthy Shetland ponies to evaluate objectively the effect of lateral heel wedges applied to the hindlimbs on both fore- and hindlimb joint motion in the sagittal and transverse plane. Additionally, the influences of feeding status and of extra training on this effect were investigated in relation to patella luxation status.

Materials and methods

Ponies

Twenty-four sound Shetland pony stallions, mean age 3 years, were used. Mean height at withers was 99 cm (range 78–107 cm) and mean weight 162 kg (range 66–227 kg). They had been assigned randomly as foals to feeding and training groups of 6 animals each. One pony from the high feeding and high training group died after the first recordings and was excluded from the study. The animals were housed in a large loose stall in which they could move freely in 2 groups of 12 ponies: one with a restricted (*Group R*) and the other with an *ad libitum* feeding (*Group A*) regimen, respectively, resulting in low (2/10) and high body condition (8/10) score. Six foals of each group (*Groups R–E: A–E*) were given alternating week by 6 or 16 sprints for 5 days a week in a horse walker at walk (40 secs at 1.4 m/sec), trot (10 secs at 3.3 m/sec) and canter (15 secs at 6.1 m/sec); the other 6 foals (*Groups R–N, E–N*) of each feeding group received no extra training.

Patella luxation score

An experienced judge of the Netherlands Shetland Pony Studbook scored, by digital palpation, in the square standing pony when a foal and at a mature age, the passive patella luxation of the left stifle joint using a score ranging from 0 (normal) to 4 (stationary patella luxation).

Markers

Plastic marker holders were glued to the skin at the lateral side of the left forelimb on the following skeletal landmarks: lateral hoof wall near ground surface and at the coronary band on a line parallel to the foot axis (Nos. 1 and 2), at the distal (No. 3) and proximal (No. 4) ends of the metacarpus, at the distal radius over the lateral styloid process (No. 5), at the proximal radius over the site of attachment of the lateral collateral ligament of the elbow joint (No. 6), at the distal humerus over the lateral epicondyle (No. 7), at the proximal humerus over the caudal part of the greater tubercle (No. 8) and at the proximal end of the scapular spine (No. 9).

In the hindlimb, the markers were glued to the following landmarks: 2 markers to the lateral hoofwall at similar locations as in the forelimb (Nos. 1 and 2), at the distal (No. 3) and proximal

TABLE 2: Transverse plane kinematics at 36% of total stride duration when the difference in stifle joint angle between the pre- and post testing conditions in the transverse plane was maximal, relative to the value at straight transverse alignment of the hindlimb (180° for stifle, tarsal and fetlock joint and 90°s for the hoof) of the total group of 23 Shetland ponies trotting on the treadmill at a speed of 3.0 m/sec under influence of feeding, training and lateral wedges

	Feeding regime					
Hindlimb stance phase	Restricted		*Ad libitum*		Overall effect	
Wedge	Pre-	Post	Pre-	Post	Wedge	Feeding
Stifle adduction	12.1 ± 1.0	14.2 ± 1.2	3.9 ± 1.1	5.3 ± 1.3	1,8*	-8,5*
Tarsal abduction	-14.7 ± 1.2	-17.8 ± 1.3	-9.4 ± 1.3	-12.0 ± 1.4	-2,9*	5,6*
Fetlock abduction	-6.4 ± 2.9	-11.2 ± 2.8	-10.1 ± 3.0	-14.7 ± 3.0	-4,7*	-3.6
Hoof adduction	3.4 ± 2.8	8.1 ± 2.9	6.1 ± 3.0	11.5 ± 3.0	5,0*	3.0

*P<0.05.

(No. 4) ends of the metatarsus, at the distal tibia over the lateral malleolus (No. 5), at the proximal tibia over the site of attachment of the collateral ligament of the stifle joint to the fibular head (No. 6), at the distal femur over the lateral epicondyle (No. 7), at the proximal femur over the cranial part of the greater trochanter (No. 8) and at the *tuber coxae* (No. 9; Back *et al.* 1999). These markers were not removed from the skin between the 2 testing conditions.

Data collection

The ponies had been accustomed to walk and trot on a treadmill (Mustang)[1] before testing took place. Two conditions were subsequently investigated, one without hoof wedges (‘pre’) and one with lateral heel wedges at both hindlimbs (‘post’). The wedges consisted of a hard plastic material that caused an elevation of the lateral side of the hoof of 5° and were applied directly after the pretesting recordings on the treadmill.

The markers were connected with a computer (CCS 68 K)[2] through a terminal which was attached to a girth strap. At a distance of approximately 8 m a modified CODA-3 apparatus was positioned perpendicular to the treadmill to record the 3 dimensional motion of the markers with a sample frequency of 300 Hz. To detect initial ground contact a one-dimensional accelerometer was glued to the hoof. Synchronously with the collection of CODA data, the signal of the accelerometer was A-D converted and stored on disc.

The same protocol was used for both conditions. First records of the left fore and hindlimb of the animal were taken standing in square position. Subsequently, records of 5 secs duration (1500 frames) were taken while the ponies were trotting at a speed of 3 m/sec. As only a maximum of 12 markers could be recorded at the same time, the forelimb was always recorded after the hindlimb. Video recordings (lateral and caudal view) were made for retrospective visual control of the data.

Data analysis

The accelerometer impact peak was used to detect initial ground contact and therefore to detect the different strides in one recorded file by determining t = 0%. The strides were checked individually by plotting the angle time diagrams of each joint subsequently on the screen. In these curves the abscissa runs from 0–100% of the total stride with steps of 0.2% and therefore 500 points are represented. When an angle time diagram from one complete stride showed abnormal peaks, due to a technical error, this stride was not used. An average of 9 strides (range 6–11) were used to calculate the mean kinematic data for every individual horse.

The standard kinematic variables of fore- and hindlimbs were evaluated in the sagittal plane. Pro- and retraction angles for the fore- and hindlimbs were calculated from the angle between markers 2 and 9 and the vertical. Scapula and pelvis rotation were calculated based on the angle of excursion between lines drawn through markers 8 and 9 with the horizontal. The angles of the stifle, tarsal and fetlock joints and the angle between the lateral hoof wall and the ground were also analysed in the transverse plane. All angles were absolute angles and not standardised to the joint angles at square stance. Data were calculated from the vertical (Z) and transverse (X) co-ordinates of the markers. When the proximal and distal joint segments are in line, the angle is 180°. More adduction means a transverse joint angle of more than 180°, while more adduction of the hoof means an angle of more than 90°.

For statistical reasons, transverse plane kinematic values were related to the value at straight transverse alignment: 180° for stifle, tarsal and fetlock joint and 90° for the hoof, so that adduction resulted in a positive value and abduction in a negative value. To correct for lateral movements on the treadmill, the x-coordinates of markers 1–8 were calculated in relation to the x-coordinate of marker 9 (*tuber coxae*). Axial rotation angles were not evaluated, as these appeared to be very small (Rathor 1968; Chateau *et al.* 2001), difficult to determine in an *in vivo* clinical set up and outside the scope of this paper. Data were not corrected for skin displacement, as correction software was developed for sagittal plane motion of mature Warmblood horses. Parallax errors due to out of plane movement of the ‘wedged’ hindlimbs have been estimated to be very small and therefore of no significant influence to the kinematic data analysis (van Weeren *et al.* 1990).

Statistical analyses

The results of individual ponies were summed and the mean ± s.d. of the total group calculated. Differences in weight and patella luxation scores in training and feeding groups at foal and mature age were evaluated in a multivariate repeated measures analysis using a general linear model with ‘age’ as within group variables and ‘feeding’, ‘training’ as between group variables. Differences in response to training, feeding and wedge were statistically evaluated in a multivariate repeated measures analysis using a general linear model with ‘limb’, ‘joint’ and ‘wedge’ as within group variables and feeding’ and ‘training’ as between group variables.

Statistical calculations were performed using the software package SPSS 9.0 for Windows. To indicate statistical significance a Plevel of 0.05 was chosen. Because of the number of variables analysed in the sagittal plane, a Bonferroni *post hoc* test was included, which increased the significance level for that plane to 0.005.

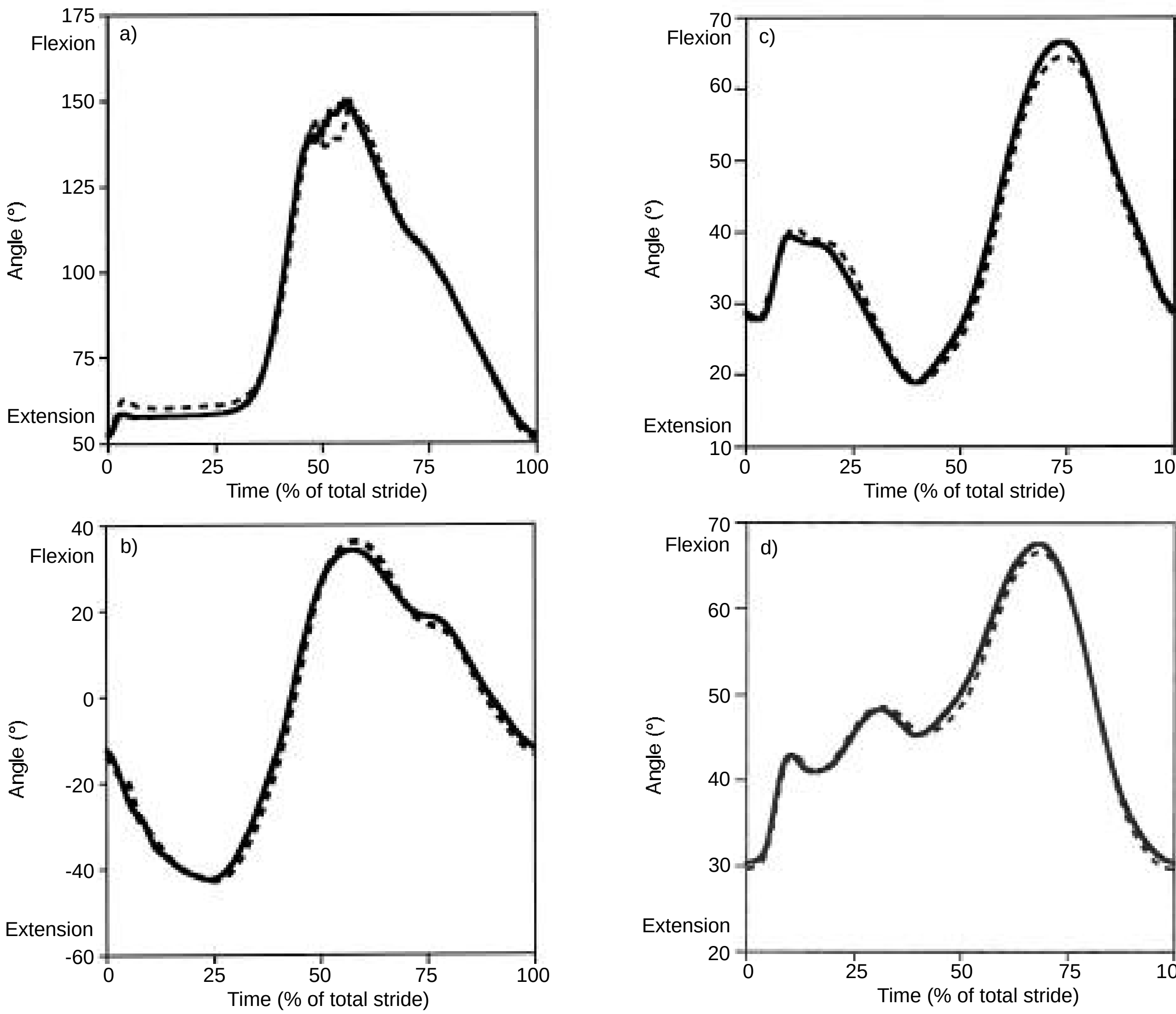


Fig 1: Joint angle-time diagrams of a) the hoof with the horizontal and of the b) fetlock, c) tarsal and d) stifle joints in the sagittal plane (solid line = without wedge, dashed line = with wedge).

Results

Bodyweight

Mean weight increased from 78 kg (range: 51–102 kg) to 162 kg (range: 66–227 kg) in the 24 animals, to 134 ± 38 kg in the restricted feeding group and to 193 ± 26 kg in the *ad libitum* feeding group ($P<0.05$) and to 173 ± 46 kg in the low training group and 151 ± 37 kg in the high training group ($P>0.05$).

Patella luxation score

Mean score increased from 1.3 ± 0.2 kg at foal to 1.8 ± 0.3 kg at mature age in *Group R* and decreased from 1.6 ± 0.3 kg to 0.9 ± 0.3 kg in *Group A* ($P<0.05$) and from 1.5 ± 0.2 kg to 1.4 ± 0.3 kg in *Groups R–E* and *A–E* ($P>0.05$).

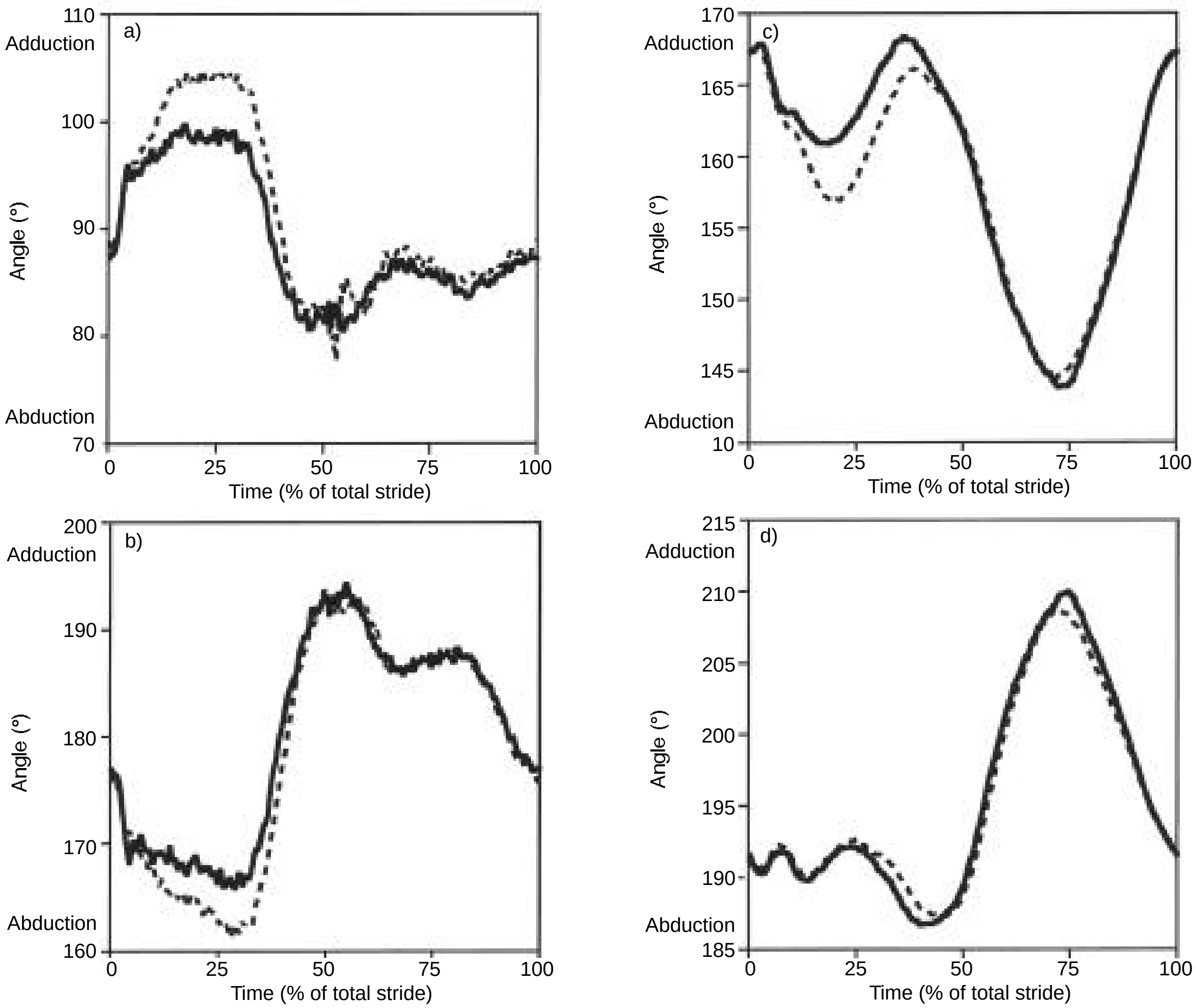
Sagittal plane fore- and hindlimb kinematics

Forelimb protraction decreased after application of the wedges and retraction increased, while hindlimb protraction increased and retraction decreased, both less than 1° (Tables 1a and b). The total range of protraction and retraction remained the same, while the range of movement of elbow, carpal, hip, stifle and tarsal joints decreased significantly by 1–2° (Fig 1). The elbow joint was maintained in a 3° more flexed position. No differences could be detected at the level of fetlock joint of the forelimb but, in the hindlimb,was 2° more flexed during the swing phase. The angle of the hind hoof by the ground surface during the stance phase increased by more than 4° after application of the lateral heel wedge.

Transverse plane hindlimb kinematics

Differences between pre- and post test conditions could be observed in all evaluated joint angles during a part of the stance phase, although the magnitude of these differences and duration became less in the proximal direction.

The angles between hoof wall and ground increased significantly after the application of the wedge ($P<0.05$) during most of the stance phase (7 to 42% of stride duration). At initial ground contact there was no difference, but directly after initial ground contact the pony placed its weight on the leg and, as a consequence of the wedge at the lateral side, the hoof was more medially rotated or more adducted. As soon as the pony lifted



Figs 2a–d: Joint angle-time diagram of a) the hoof with the horizontal and of the b) fetlock, c) tarsal and d) stifle joints in the transverse plane (solid line = without wedge, dashed line = with wedge).

the leg, the angles in both conditions decreased and the difference was eliminated. No differences could be observed during the swing phase (Fig 2a). The joint angles at the fetlock joint were significantly smaller ($P<0.05$) after appliance of the wedge during most of the stance phase (10 to 42 % of total stride), while during the swing phase no differences could be observed (Fig 2b). The situation in the tarsal joint was similar to that in the fetlock, although the course of the curve was different (Fig 2c). In the first part of the stance phase the angles decreased but, after approximately 20% of total stride time, increased; and decreased again during the first part of the swing phase. The joint angles of the tarsal joint were significantly smaller with the wedge from 10 to 42% of stride duration ($P<0.05$) but differences were present during the swing phase. The stifle joint showed a different pattern (Fig 2d). The shape of the curve during the stance phase was sinusoidal and it was not until 32% of total stride duration that the angle with wedge became larger ($P<0.05$) than without wedge. After 40% of total stride duration, the angles in both conditions increased and a difference could no longer be observed. The stifle joint was the only joint which showed a difference between the 2 conditions during the swing phase, from 52 to 58% of the total stride time the stifle angle was smaller in the condition with the wedge ($P<0.05$). In this joint, the difference between pre- and post testing conditions was largest at 36% of total stride duration. At this time point, adduction was 1.8° more with the wedge. At the same moment the tarsal joint was 2.9° and the fetlock joint 4.7° more abducted. The position of the different segments with regard to each other is shown in Figure 3. The lines between 2 markers represent the segment on which the markers were placed. After the appliance of the wedges most segments were positioned more medially when looking at the average relative distances in x-direction, with and without wedges, at 36% of total stride duration this was 0.2 cm difference at marker No. 1 (distal hoof), 0.4 cm at marker No. 2 (proximal hoof), 0.5 cm at marker No. 3 (fetlock joint), 1.1 cm at marker No. 4 (proximal metatarsus), 0.9 cm at marker No. 5 (distal tibia), 0.8 cm at marker No. 6 (proximal tibia), 0.3 cm at marker No. 7 (distal femur) and 0.1 cm at marker No. 8 (proximal femur). The differences between the 2 conditions found at marker Nos. 1, 7 and 8 were less than or close to the resolution of CODA and were not significant ($P>0.05$), whereas at marker No. 4, proximal part of the metatarsus, the wedge effect in the transverse plane was significant ($P<0.05$).

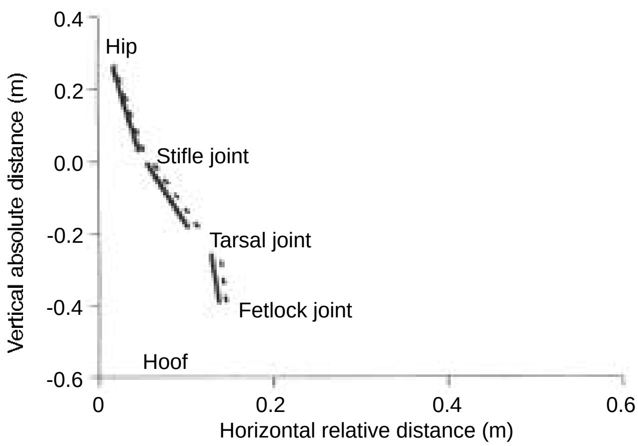


Fig 3: The position of the left hindlimb segments in a caudal-cranial view at 36% of total stride duration when the difference in stifle joint angle between the pre- and post testing conditions in the transverse plane was maximal (solid line = without wedge, dashed line = with wedge). The vertical distance is the absolute z-coordinate of the marker recorded by CODA-3, the horizontal distance is the x-coordinate of which that of marker 9 was subtracted.

Influence of feeding

In the sagittal plane (*Group R*) ponies, demonstrated a flatter gait than *Group A*. In the transverse plane, at 36% of total stride duration, stifle joint adduction was 8.5° and tarsal joint abduction 5.6° more than in *Group R* ($P<0.05$, Table 2).

Influence of training

There was no significant effect on temporal or angular kinematics as a result of sprint training.

Discussion

This study was conducted to evaluate objectively the effect of lateral wedges applied to the hindlimbs on both fore- and hindlimb joint kinematics in the sagittal and transverse plane and to investigate the influence of specific feeding and training regimes. Shetland ponies were used because possible effects were considered to become more easily detected than in mature horses, as the used wedges were relatively large. A treadmill was used to maintain the influence of speed on kinematics to a minimum, while the use of a 3-dimensional recording equipment, operating at high frequency level, was obligatory for the reliable detection of differences that were expected to be minimal.

Skin displacement is a well known source of substantial errors when using kinematic analysis techniques based on skin markers. In mature Dutch Warmblood horses, errors of up to 4 cm at the shoulder joint and 15 cm at the hip joint have been reported (van Weeren *et al.* 1990). Although these values can be supposed to be much less in Shetland ponies, the relative error can be expected to be of the same magnitude. Correction algorithms have been calculated, but these are valid only for the Dutch Warmblood or breeds with a similar size and for sagittal plane kinematics (van Weeren *et al.* 1990). However, the same authors state that correction for skin displacement is not necessary when comparing 2 or more groups of comparable animals. Therefore, it was deemed justified in the present study to neglect the influence of skin displacement. Nevertheless, it is realised that the different body conditions may have influenced skin displacement to some extent. The values found for the most proximally located joints should therefore be interpreted with some caution.

Recordings were always done in the following order: hindlimb without, forelimb without, then hindlimb with and forelimb with wedges. The kinematics of the forelimbs were also taken into account to registrate indirect effects of the wedges on locomotion. The duration of the tests seemed too short for fatigue to play a role in the results, which would have necessitated a Latin Square design. Furthermore, this would have interfered with recordings for an other, longitudinal study in the same animals (Back *et al.* 2002).

Axial rotational angles were not evaluated, because these appear to be very small and are rather difficult to determine in an *in vivo* clinical set up. Chateau *et al.* (2001) found, in an *in vitro* study, a mean medial rotation of only -0.9° in the fetlock joint of 4 equine cadaver limbs subjected to a load of 6000 N and a 12° lateral wedge. In the same study, it appeared that wedges did not significantly alter the amplitude of extension of the fetlock joint angle in the sagittal plane. Transverse angles can be caused by a combination of rotation and abduction or adduction. However, as these rotations appeared to be smaller than one degree in the joint near the wedged foot, using a nearly 3 times bigger wedge as used in this study, this influence is probably even less in the stifle joint. Rathor (1968) reported that 'when the femur approaches the position of extreme extension it undergoes a limited, although visible, inward rotation'. Therefore, a 3 x 2D approach was chosen for data analysis, in which only angles in the sagittal and transverse plane seemed relevant. Data at a certain time point at stance were statistically compared before and after wedging, demonstrating an effect on hindlimb position in the sagittal and transverse plane; the 3D motions which were exactly responsible for this change in posture was outside the scope of this study.

Parallax errors may have been caused by a viewing angle (α) that was not exactly 90° due to out of plane movements of the 'wedged' hindlimbs in this study. Van Weeren *et al.* (1990) investigated this phenomenon in the upper limb parts of the limbs with a horse trotting an a treadmill and found that α did not exceed 18°. These errors resulted in a worst case estimate for the total parallax error of 7.2 mm, which amounts to 5.1 mm per component (X or Y). These errors were considered to be very small and therefore of no significant influence to the kinematic data analysis. Furthermore, wedges did not result in the maximal parallax errors as evaluated by van Weeren *et al.* (1990).

After appliance of the wedges, the range of elbow, carpal, hip, stifle and tarsal joint movement were 1–2° smaller. The forelimb was kept more retracted and the hindlimb more protracted, together with 3° more flexion of the elbow joint. Apparently, the acute application of lateral heel wedges resulted in a more compact, less animated trot. Firth *et al.* (1988) investigated, over 10 days, the influence of a wedge that was higher laterally than medially, on the bone strain of the metacarpus in 9 clinically and conformationally normal foals. In first instance, strain values recorded from the medial surface of the metacarpus decreased about 40% and the lateral surface, the compressive strain increased by more than 100%. However, these differences became less during the course of 10 days and significant differences could no longer be observed after 10 days. Therefore, it seems reasonable that if there was a longer period of post testing recordings, i.e. 2 days as in Willemen *et al.* (1999), these general effects could have been compensated for, but also the specific effects would have become undetectable. In this study, direct measurement did not permit the pony to compensate fully for these general and specific effects. It is clear that the posture of the hindlimb has changed through the application of wedges. The weight of the pony causes a lateroflexion at the fetlock joint, because the wedge lifts the lateral side of the foot during stance phase (Firth *et al.* 1988). The tendons and ligaments at the fetlock joint prevent a lateroflexion and, in this way, compensate for elevation (Chateau *et al.* 2001). Therefore, the metatarsus is under more pressure laterally and there is lateroflexion at the tarsus. Because the hip is fixed, the proximal segments must compensate the medial position of the distal segments. This results in an adduction of the stifle joint of up to 1.8°, which may lead to a slightly lower tension in the medial patellar ligament. This ligament is attached to the *cartilago parapatellaris*, which moves over the medial trochlea in case of patella fixation. The application of lateral wedges therefore has a relieving effect on this condition. A concomitantly induced tibial endorotation might compensate for the endorotation of the femur at the end of the stance phase (Rathor 1968). At the same time, the tarsal joint abducted 2.9° and the fetlock joint 4.7°. This additionally decreases pressure on the medial side of the tarsal joint, which can have a beneficial effect on bone spavin. However, the fetlock joint has to experience considerably more out of plane stress, eventually leading to injuries of the proximal phalanx, the sagittal ridge of the metatarsus or the collateral ligament (Chateau *et al.* 2001). Colahan *et al.* (1991) investigated the influence of the application of both lateral and medial wedges in the forelimb on the centre of pressure in cadaver limbs and in standing young Quarterhorses. Their conclusion was that, in both conditions, the centre of pressure of the hoof shifted in the direction of the wedge. Wilson *et al.* (1998) obtained similar results as Colahan *et al.* (1991), but found a less pronounced difference after application of a lateral than with a medial wedge. They suggest that the horse adopts a stance with the hindlimbs further apart. This would return the centre of pressure towards its normal position, which is also one of the explanations for the previously quoted findings of Firth *et al.* (1988).

In the sagittal plane, restricted feeding resulted in a flatter, less animated trot. This is similar, though more pronounced, to the decrease in hindlimb flexion as a result of wedging. The explanation for this phenomenon is not clear (Back *et al.* 2002). The increase in weight from foal to mature was twice that in the higher than in the lower condition group. It may be hypothesised that this increase in weight in itself led to a change in gait, or that the ponies in this group could dispose of more energy, trotting at the same velocity with significantly more maximal joint flexion (relative to initial ground contact) of elbow, carpal, stifle, tarsal and hind fetlock joints, resulting in a notably more animated gait (Back *et al.* 2002) and, apparently, more hindlimb stability in the transverse plane. The restricted feeding group demonstrated a patella luxation score twice that of the *ad libitum* feeding group, which fully coincided with effects on motion in the transverse plane. The stifle joint showed 5 times more adduction and the tarsal joint twice that abduction than with a lateral wedge.

Extra sprint training on top of free paddock exercise did not significantly influence kinematics. This is in contrast to a recent study in which sprint training substantially improved the locomotor efficiency of the hindlimbs (Back *et al.* 1999). However, that was training on top of a box rest regimen, whereas the animals in our study were allowed to move freely in a loose box. In the former study, the effect disappeared when the box rested horses received the same free paddock exercise as the group of horses with which they were compared. Sprint training on top of box rest could therefore replace only partially the effect of free pasture exercise on locomotor development (Back *et al.* 1999) while, in the present study, sprint training on top of free paddock exercise did not (further) improve the locomotion of ponies (Back *et al.* 2002).

In conclusion, this study showed that, although the measured differences are small, lateral heel wedges have acute, specific effects on fore- and hindlimb motion. Future research, in which chronic and *in vitro* effects are studied, should prove that this type of orthopaedic shoeing may relieve pressure long term on the sites affected. This would scientifically confirm age-old empirical practices to treat patella fixation and bone spavin with lateral heel wedges. Moreover, poor body condition, because of restricted feeding resulted in a much worse patella luxation score, while the effects on stifle and tarsal joint movement in the transverse plane were considerably larger than with a lateral wedge. These findings emphasise the clinical importance of general body condition for maintaining lateral stability in the equine hindlimbs. Longitudinal training effects, however, could not be detected.

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Manufacturers'addresses

[1]Kagra AG, Fahrwangen, Switzerland.
[2]Compcontrol, Eindhoven, The Netherlands.

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